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(71) Applicant (for all designated States except US): THE UNIVERSITY OF SYDNEY [AU/AU]; Parramatta Road, Sydney, NSW 2006 (AU).

(72) Inventor; and
(75) Inventor/Applicant (for US only) : BASSETT, Ian, Masson [AU/AU]; 60 Milray Avenue, Wollstonecraft, NSW 2065 (AU).

(74) Agent: GRIFFITH HACK & CO.; 71 York Street, Sydney, NSW 2000 (AU).

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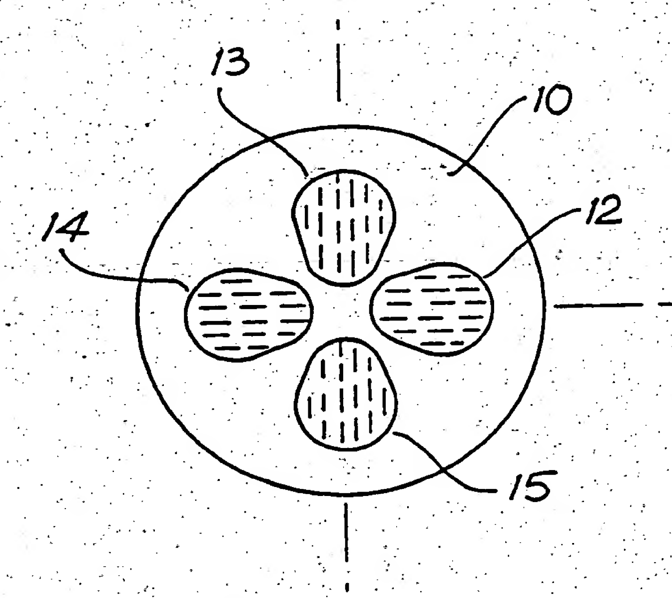
(54) Title: CIRCULARLY BIREFRINGENT OPTICAL FIBRE



(57) Abstract

A single mode circularly birefringent optical fibre having a central core and a surrounding cladding. The core (10) contains four symmetrically disposed core regions (12 to 15) each of which has an average refractive index greater than that of the surrounding portions of the core and each of which follows a helical path. Diametrically disposed ones of the core regions have a common direction of maximum electric polarisability, whereby they exhibit effective linear material birefringence, and orthogonally disposed pairs of the regions have orthogonal directions of maximum electric polarisability. The cross-section of the core has four-fold symmetry, in that the physical geometry of any given cross-section of the core recurs with successive rotations of the core through 90°.

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CIRCULARLY BIREFRINGENT OPTICAL FIBRE

TECHNICAL FIELD

This invention relates to a single mode optical fibre that exhibits circular birefringence.

Optical fibres that exhibit circular birefringence are characterised in that they facilitate the transmission of circularly polarised light and they accommodate different velocities of transmission of right hand and left hand circularly polarised light. This characteristic renders circularly birefringent optical fibres suitable for use in coherent communication systems and in sensing systems, and a particularly important application of such optical fibres is in the field of electric current sensing, where the optical fibres may be employed in circuits which have been proposed for obviating the need for current transformers.

Although the characteristics and benefits, or at least some of the benefits, of circularly birefringent optical fibres are well known and understood, such fibres have not been produced on a commercial scale and it is understood that they have not yet been produced successfully or consistently on an experimental scale. This is because a complete understanding has not hitherto been obtained in respect of the physical characteristics which should be possessed by an optical fibre in order that it might accommodate the transmission of circularly polarised light.

BACKGROUND ART

European Patent Application No.EP 0 227 366 A2 dated December 8 1986 by the University of Southampton discloses a single mode optical fibre which is said to exhibit circular birefringence and which is characterised by an azimuthally inhomogeneous spun core. The inhomogeneity is created so as to exclude significant linear birefringence and it is achieved by forming the core with at least one lobe which has a refractive index greater than that of the immediately adjacent core material. European Patent Application No.EP 0 210 806 A2 dated July 18 1986 by Pirelli General plc is directed to an optical fibre which apparently has much the same sort of structure as that which is disclosed in EP 0 227 366 A2.

However, it is believed that mere azimuthal inhomogeneity in and spinning of the core will not result in circular birefringence, and it is proposed in accordance with the present invention that the optical fibre must effectively incorporate two regions which each exhibit effective linear material birefringence, with the respective regions having orthogonal directions of maximum electric polarisability.

DISCLOSURE OF THE INVENTION

Thus, the present invention provides a single mode circularly birefringent optical fibre which comprises a central anisotropic core and a cladding surrounding the

core, the cladding having a diameter significantly greater than that of the core and a refractive index less than that of the core. The core is formed within its cross-section with four symmetrically disposed regions, each of which has an average refractive index greater than that of the surrounding portions of the core and each of which follows a helical path which extends coaxially with and in the longitudinal direction of the core. Diametrically opposed ones of the regions have a common direction of maximum electric polarisability, whereby they exhibit effective linear material birefringence, and orthogonally disposed pairs of the regions have orthogonal directions of maximum electric polarisability.

The cross-section of the core as above defined has what might be regarded as four-fold symmetry with respect to the axis of the core, in the sense that the physical geometry of a given cross-section of the core recurs with successive rotations of the core through 90°.

Creation of the four regions of enhanced anisotropic refractive index may be achieved by stressing the core material within the regions, and various techniques may be adopted for effecting either self induced or externally induced stress fields. For example, a doped material having a co-efficient of thermal expansion different from that of adjacent material may be located in a preform of the fibre at positions surrounding the core (either inside or outside the interface with the cladding), so that stress fields will

be induced in the four regions during solidification of the fibre after drawing from the preform.

As an alternative to stressing the core material within the core regions, effective linear material birefringence may be realised by forming each of the core regions from a composite structure which simulates an anisotropic refractive index distribution. The composite structure in each region may be composed of a sandwich structure having thin alternating layers with different isotropic refractive indices.

The core regions are caused to follow a helical path by spinning the preform during the fibre drawing operation, with the relationship of the preform spin rate and the fibre drawing rate being adjusted so as to produce the required pitch or, expressed alternatively, the number of spiral convolutions per linear metre of the optical fibre.

The optical fibre preferably has a core dimension in the order of 10 μm and an outer (cladding) diameter in the order of 100-150 μm.

The invention will be more fully understood from the following description of a preferred embodiment which is illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Figure 1 shows a greatly magnified cross-sectional view of an optical fibre;

Figures 2A, 2B and 2C show further magnified cross-sectional views of alternative core portions of the optical fibre shown in Figure 1; and

Figures 3A and 3B show representations of regions within the core portion which are enhanced, as to their refractive indexes, for horizontally and vertically polarised light respectively.

MODES FOR CARRYING OUT THE INVENTION

As shown in Figure 1 of the drawings the optical fibre has a core 10, which is to be described in greater detail with reference to Figures 2 and 3, and a cladding 11. The core has a diameter typically in the order of 10 µm and the cladding has a diameter in the order of 125 µm to conform with what has become an international standard.

The core 10 is formed from doped silica and the cladding 11 is formed, normally, from pure silica; although other materials may be used. In general, the techniques which are conventionally employed for forming optical fibres may, with the necessary changes, be employed in forming the fibre which is described in this specification. Thus, a pre-form may be constructed using a more-or-less conventional approach, and twisting or helical forming may be effected using the conventional spinning technique which has been referred to briefly in a preceding passage of this specification.

As shown in the further magnified illustration of Figure 2A, the core is formed within its cross-section with four symmetrically disposed lobes 12-15, each of which has a refractive index greater than that of the surrounding regions of the core. Each of the lobes is stressed in a manner such that the diametrically disposed lobes 12, 14 in one case and 13, 15 in the other case have common directions of maximum electric polarisability, in the directions indicated in the respective cases by the broken lines.

The core structure 10 that is shown in Figure 2B is similar to that of 2A except that, whereas in Figure 2A the enhanced electric polarisability in each lobe lies in a direction which is parallel to the axis of the lobe, the lobes 16-19 in Figure 2B have enhanced electric polarisability in directions that are normal to the axes of the respective lobes. However, it will be observed that, in the structures of both Figure 2A and 2B, the orthogonally disposed pairs of core regions 13, 15 and 12, 14 in Figure 2A and 17, 19 and 16, 18 in Figure 2B have orthogonal directions of maximum polarisability.

The lobe regions 12-15 and 16-19 may be formed by locating appropriately doped rod-shaped inclusions of silica (not shown) in the pre-form prior to drawing of the fibre. The doping is contrived to cause a differential expansion between the inclusions and the surrounding material, so that stresses are induced in the lobe regions during the drawing and subsequent freezing of the core material. The stressing

in turn results in material anisotropy as indicated in Figures 2A and 2B, with the lobes defining regions in which the refractive index effective for light polarised in the given directions is enhanced.

As an alternative to stressing the core material within the four core regions, the desired effective material birefringence may be achieved by forming each of the core regions from a composite structure which simulates an anisotropic refractive index distribution. As shown in Figure 2C, the composite structure in each of the core regions 20 to 23 is composed of a sandwich structure which is itself formed from a plurality of thin alternating layers 24 and 25 having different isotropic refractive indices. Here again, the diametrically disposed regions 20, 22 in one case and 21, 23 in the other case have common directions.

The refractive index in the centre of the core region does not exhibit anisotropy because of the requirement of four-fold rotational symmetry. The refractive index in the centre of the core region should however have a magnitude similar to that of the lobe regions.

The refractive index in the remainder of the core 10, that is between and surrounding the lobe regions 12-15 and 16-19 need not exhibit material anisotropy, but the magnitude of the refractive index must be generally less than that of the lobe regions and central area of the core.

The cladding 11 is composed of a material which has a lower refractive index than that of the core.

As a result of the refractive index distributions, "horizontally" polarised light tends to concentrate in the region of the core which is shown in Figure 3A and "vertically" polarised light in the region shown in Figure 3B, in respect of the core configuration which is shown in Figures 2A and 2C. However, in the case of the core configuration shown in Figure 2B, the patterns shown in Figures 3A and 3B are reversed.

Although not shown in the drawings, each of the lobe regions 12-15 and 16-19 follow a helical path which extends coaxially with and in the longitudinal direction of the core. This is achieved by spinning the pre-form when drawing the fibre to its required cross-sectional dimension. The pre-form spin rate and the fibre drawing rate is adjusted so as to produce the required pitch or, expressed alternatively, the required number of spiral convolutions per linear metre of the optical fibre.

When linearly polarised light passes through a circularly birefringent fibre, its direction of polarisation rotates. The magnitude of the birefringence is by definition equal to twice the rotation in radians divided by the length of the fibre in metres. Provided the pitch length p is not too short, the fibre has a circular birefringence of magnitude:

$$(4 \pi/p)(1-\gamma) \text{ rad/metre}$$

where $0 < \gamma < 1$

The pitch length p would normally be within the range 1mm to 10mm.

Thus, the maximum value of the birefringence is $4\pi/p$ corresponding to the direction of polarisation of light passing through the fibre turning at the rate $(0.5)\times 4\pi/p = 2\pi/p$ rad/metre, equal to the rate at which the fibre cross-section itself turns. In general, the rate of turning of the direction of polarisation is less than this, since it does not "keep up with" the orientation of the fibre cross-section. To make the birefringence as high as possible, γ must be made as small as possible. The value of γ is determined by the details of the anisotropic refractive index distribution illustrated in Figures 3A and 3B and, if x_a is the (positively signed) fundamental solution of the scalar wave equation corresponding to the refractive index distribution of Figure 3A and x_b is the similar solution corresponding to Figure 3B, then

$$\gamma = \quad dx\ dy\ x_a x_b / [\quad dx\ dy\ x_a^2 \quad dx\ dy\ x_b^2]^{1/2}$$

It is important that, in the absence of effective material anisotropy, the refractive index distribution seen by horizontally and vertically polarised light is the same. Consequently, $x_a = x_b$ and, as follows from substitution in the above expression for γ, $\gamma = 1$ and consequently the birefringence is 0.

The lobe regions 12-15 and 16-19 occupy a substantial proportion of the cross-section of the core 10 and,

consequently, they lie close enough together that the whole structure constitutes a single wave guide rather than a number of independent wave guides. This may be expressed by the statement that the "beat length" for exchange of power between diametrically opposite lobe regions is short in comparison with the pitch length p.

THE CLAIMS

1. A single mode circularly birefringent optical fibre which comprises a central anisotropic core and a cladding surrounding the core, the cladding having a diameter significantly greater than that of the core and a refractive index less than that of the core, the core being formed within its cross-section with four symmetrically disposed regions, each of which has an average refractive index greater than that of the surrounding portions of the core and each of which follows a helical path which extends coaxially with and in the longitudinal direction of the core, diametrically opposed ones of the regions having a common direction of maximum electric polarisability, whereby they exhibit effective linear material birefringence, and orthogonally disposed pairs of the core regions having orthogonal directions of maximum electric polarisability.

2. The optical fibre as claimed in claim 1 wherein each of the core regions is defined by a region of stressed core material.

3. The optical fibre as claimed in claim 2 wherein a stress inducing material having a coefficient of thermal expansion different from that of adjacent material is located in the optical fibre at positions surrounding the core regions.

4. The optical fibre as claimed in claim 3 wherein the stress inducing material is located outside of the interface of the core and the cladding.

5. The optical fibre as claimed in claim 1 wherein each of the core regions is formed from a composite structure which simulates an anisotropic refractive index distribution.

6. The optical fibre as claimed in claim 5 wherein each core region is constituted by a sandwich structure having alternating layers with different isotropic refractive indices.

7. The optical fibre as claimed in any one of the preceding claims wherein the core is formed from doped silica.

8. The optical fibre as claimed in claim 7 wherein the cladding is formed from substantially pure silica.

9. The optical fibre as claimed in any one of the preceding claims wherein the core has a diameter in the order of 10μm and the cladding has an outside diameter in the range 100–150μm.

10. The optical fibre as claimed in any one of the preceding claims wherein the pitch length of the helical path is in the range 1mm to 10mm.

11. A single mode circularly birefringent optical fibre substantially as hereinbefore described with reference to Figure 1 and Figures 2A, 2B or 2C of the accompanying drawings.

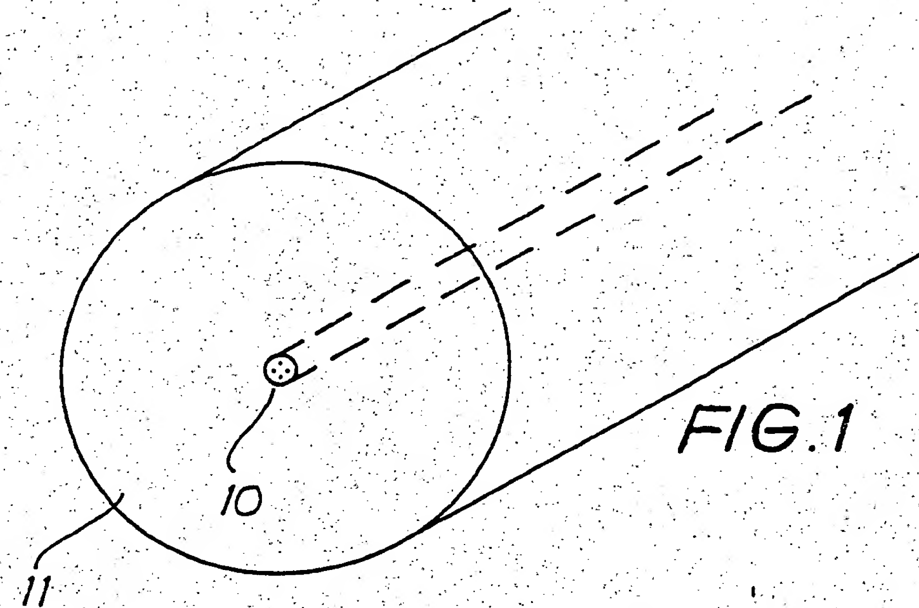

FIG.1

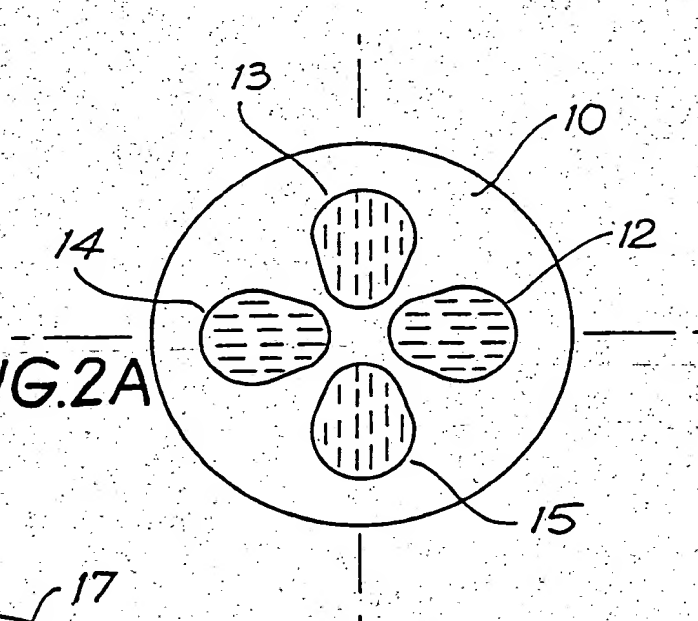

FIG.2A

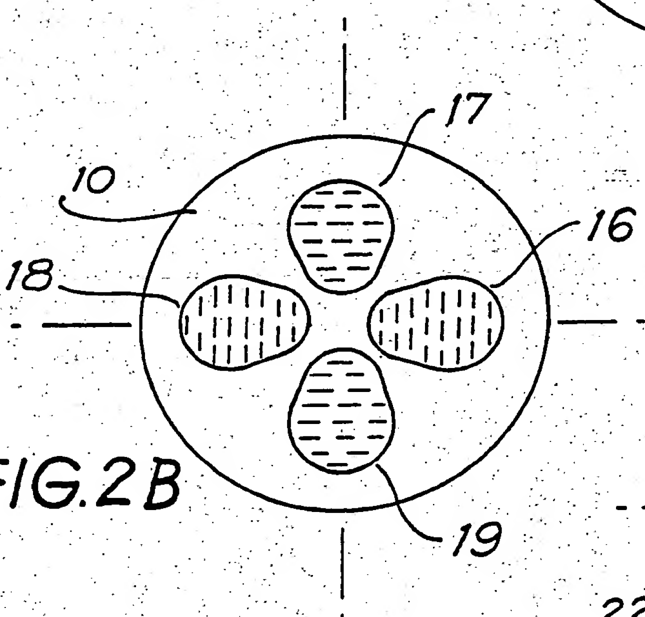

FIG.2B

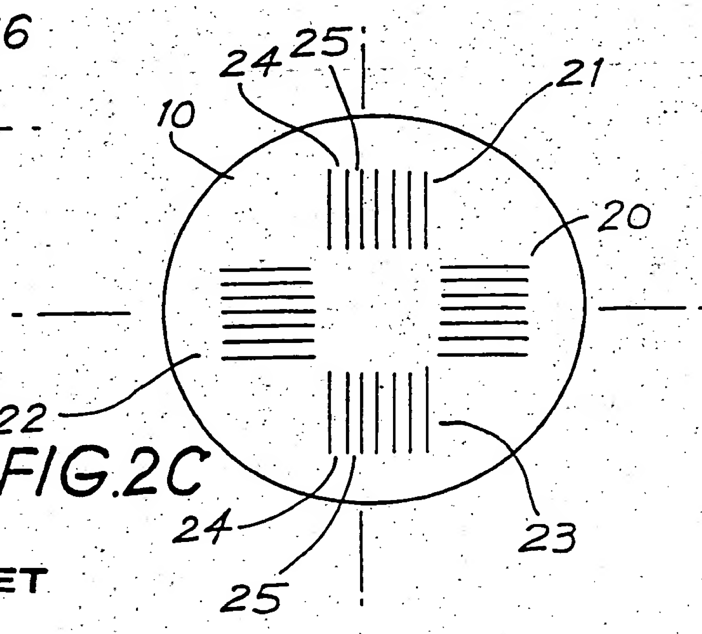

FIG.2C

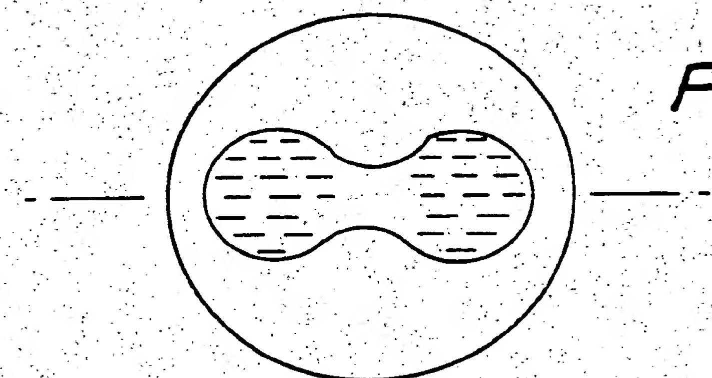
FIG. 3A

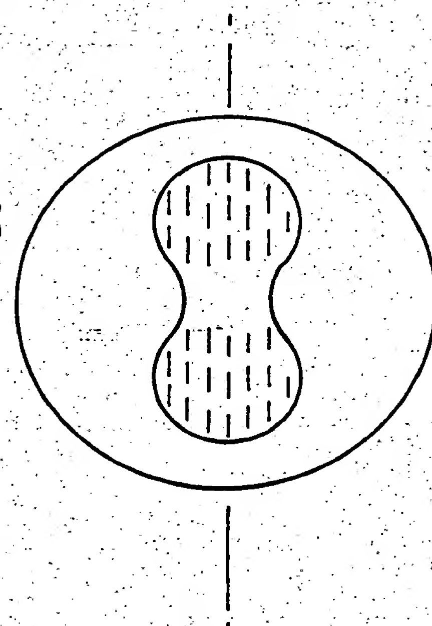
FIG. 3B

INTERNATIONAL SEARCH REPORT

International Application No. PCT/AU 89/00187

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.^{4} G02B 6/16

II. FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System	Classification Symbols
IPC	G02B 6/16, 5/172, C03C 13/00, 13/04

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

AU : IPC as above, Australian Classification 00.4

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category*	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No 13
A	AU,A, 28751/84 (BHAGAVATULA et al) 6 December 1984 (06.12.84)	(1,6)
A	Patents Abstracts of Japan, P-119, page 17, JP,A, 57-26810 (NIPPON DENSHIN DENWA KOSHA) 13 February 1982 (13.02.82)	(1)
A	Derwent Abstract Accession no. 85-273680/44, Class V07, JP,A, 60-186432 (SUMITOMO ELEC IND KK) 21 September 1985 (21.09.85)	(1,2)
A	Patents Abstracts of Japan, C-358, page 2, JP,A. 6 1-36130 (NIPPON TELEGR & TELEPH CORP) 20 February 1986 (20.02.86)	(1)
A	Derwent Abstract Accession no. 86-308950/47, Class V07, JP,A, 61-228404 (SUMITOMO ELEC IND KK) 11 October 1986 (11.10.86)	(1,2,3,4)

* Special categories of cited documents: 10

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
6 July 1989 (06.07.89)	19 July 1989 (19.07.89)
International Searching Authority	**Signature of Authorized Officer**
Australian Patent Office	E.J. KNOCK E.J. Knock

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON
INTERNATIONAL APPLICATION NO. PCT/AU 89/00187

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members		
AU 28751/84	BR 8402407	DK 2683/84	EP 128024
	ES 532804	FI 842183	IL 71740
	JP 59232301	NO 842176	US 4549781

END OF ANNEX